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Kingdom Community Wind
Shadow Flicker Analysis

Introduction

Vermont Environmental Research Associates (VERA) performed a shadow flicker analysis of the proposed Kingdom Community Wind Project (KCW) in Vermont for Green Mountain Power. Twenty one GE 2.5 XL wind turbines with 85 meter hub heights and 100 meter rotor diameters are modeled in this analysis.

Background

Wind turbine shadow flicker is the alternating changes in light intensity that occurs when the rotating wind turbine blades pass in front of the sun. Shadow flicker can occur only when certain meteorological conditions are present, usually during the morning and evening hours when the sun is at a low angle in the sky. Meteorological conditions must be such that the rotor plane of rotation is close to perpendicular to the line between the sun and the viewer and the sun's rays are not obstructed or diffused from cloud cover or area fog. Obstacles such as terrain, trees, or building structures significantly reduce or block shadow flicker from occurring at a give location. Shadow flicker effects are measured in units of time or duration, typically number of hours per year.

Shadow flicker intensity at a given location is the difference in brightness in the presence or absence of a shadow. The intensity of the shadow flicker is strongest near the wind turbine and diminishes with distance from the turbine. At distances greater than 2000 meters (6,562 feet) from the turbines, the frequency of shadow flicker occurrences is low and its intensity is faint enough to not be a distraction to human activities. Computer modeling software can accurately calculate the potential locations and durations of shadow flicker and is typically calculated for distances up to 2000 meters from the wind turbines. However, these analyses do not evaluate intensity and therefore, conservatively, worst-case intensity is assumed throughout the study area.

Shadow flicker frequency is related to the number of blades on the rotor and the rotor speed. Wind turbines considered in this project use three-bladed rotors, 90 to 100 meters diameter, with rotational speeds up to 17 rpm.[1]

Modeling Approach

Using the computer modeling software WindPro, two shadow flicker analyses were conducted and maps produced to display the results.

First, a "worst case" analysis was conducted; calculating the number of hours per year shadow flicker could be expected assuming 1) a "bare" landscape with no trees, 2) weather conditions with no cloud cover or fog, and 3) the wind turbines operating every hour. The data sources input for the analysis are:

Input Data	Data Source
Wind turbine locations	Entered as geographic coordinates
Wind turbine rotor diameter	GE 2.5xl - 100 meters
Wind turbine hub-height	GE 2.5xl - 85 meters
Digital elevation and base map data	USGS 1 Arc-Second SRTM Digital Elevation Model (DEM), and 1:24,000 scale USGS topographic base map

A second analysis was performed to represent an "expected", more realistic scenario that incorporates land cover, local climate, and turbine availability. In addition to the above inputs, the following additional data sets were input to the model for this second analysis:

Input Data	Data Source
Monthly sunshine probabilities Monthly probabilities of obstruction of the sun from low level cloud cover	Morrisville VT National Oceanic and Atmospheric Administration (NOAA) station over the period 2003-2009 long-term reference data
Land cover data	National Land Cover Dataset 2001-Vermont, obtained from Vermont Center for Geographic Information to identify forested areas.
Joint wind speed and direction frequency distribution data	Measurement Station 808 wind data collected over the period June 2003 – May 2008

Both analyses reflect the following inputs:

Parameter	Setting
Time Set for calculations	Every 1 minute of every day over one full year
Operating mode	Turbines available to operate all the time
Minimum elevation angle of the sun to	3 degrees above horizon

[1] This is less than 0.8 Hz (less than one "flicker" per second) which is a frequency that is harmless to humans. Higher frequency flashes of light, such as those from a strobe light, can trigger seizures in photosensitive individuals. The Epilepsy Foundation reports frequencies between 5 to 30 flashes per second are the most likely to trigger seizures. (see: http://www.epilepsyfoundation.org/about/photosensitivity/index.cfm for further information).

Parameter	Setting
calculate shadow effects	
Maximum distance from each wind turbine location for calculation	2000 meters (6560 ft.)
Resolution of calculation points	10 meter (32.8 ft.) square grid cells
Receptor orientation	"green house" (exposed to light from all directions)
Height and size of Receptor	1 meter (3.28 ft.) off ground and 1 square meter (10.8 sq ft.) in size

Using the data sources and assumptions described above, the WindPro SHADOW module simulates the path of the sun over a year at the latitude and longitude of the site. For each time step, the model calculates the location of the sun in relation to the turbine locations, factoring in operational hours and sunshine probability for the time period. For each 10m (10.28 ft.) grid cell within 2000m (6560 ft.) of a turbine location, the model calculates whether or not there is a direct line of sight between the grid cell location and wind turbine using the elevation data. These calculations are paired to result in the number of hours per year of shadow flicker that could be expected at each 10m grid cell within 2000m of the turbine sites. Results of these calculations are shown in the attached maps as Figure 1 (worst case) and Figure 2 (expected case).

Conclusions

Based on this analysis and our experience with similar analyses performed for other wind projects, it is our opinion that the estimated shadow flicker as shown in Figures 1 and 2 will not present an undue adverse effect on human activity in the area of the Kingdom Community Wind project.

In actuality, shadow flicker is likely to be less than shown in the maps because of the conservative simplifications used in the modeling exercise. For example, the model does not account for buildings, shrubs or other obstacles that would block the turbines from view and thereby reducing the shadow flicker phenomenon. Secondly, the model does not show the intensity of flicker, only the presence or absence of flicker. As the distance increases away from the turbine locations, the intensity of the shadow diminishes. Lastly, this model does not incorporate a factor specifying the percentage of the sun's area covered by the turbine blade. As this percentage decreases, either by the sun location or the viewing distance from the turbine, the shadowing effect decreases dramatically.

Kingdom Community Wind
Orleans County Vermont

Shadow Flicker Figure 1

Shadow Flicker Analysis - "Worst Case"
Within 2000 meters of wind turbine locations
Bare earth conditions, no trees
100% sunshine
Wind turbines operating at all times

Modeled: Twenty-one GE 2.5XL wind turbines

GE 2.5XL turbine location (4/2010)

"Worst Case" Hours per Year Contours

- 1 hr/yr
- 10 hrs/yr
- 25 hrs/yr
- 50 hrs/yr
- 100 hrs/yr
- 200 hrs/yr

VT-911 Structure locations

- Residential structures
- Seasonal structures
- Town boundary
- County boundary

Data:
Public data formated from the Vermont Center for Geographic Information's website. VT-911 (2008) updated for 606 Farm Rd - residential (R1) and 2122 Irish Hill Rd. - seasonal (R5). Base map: USGS National Map Server DRG 1:24,000. Kingdom Comunity Wind (KCW) data proprietary.

1,000 500 0 1,000
Meters

2,500 1,250 0 2,500
Feet

N W E S

Prepared for:
Green Mountain Power Corp.

Vermont Environmental Research Associates
Waterbury Center, VT www.northeastwind.com
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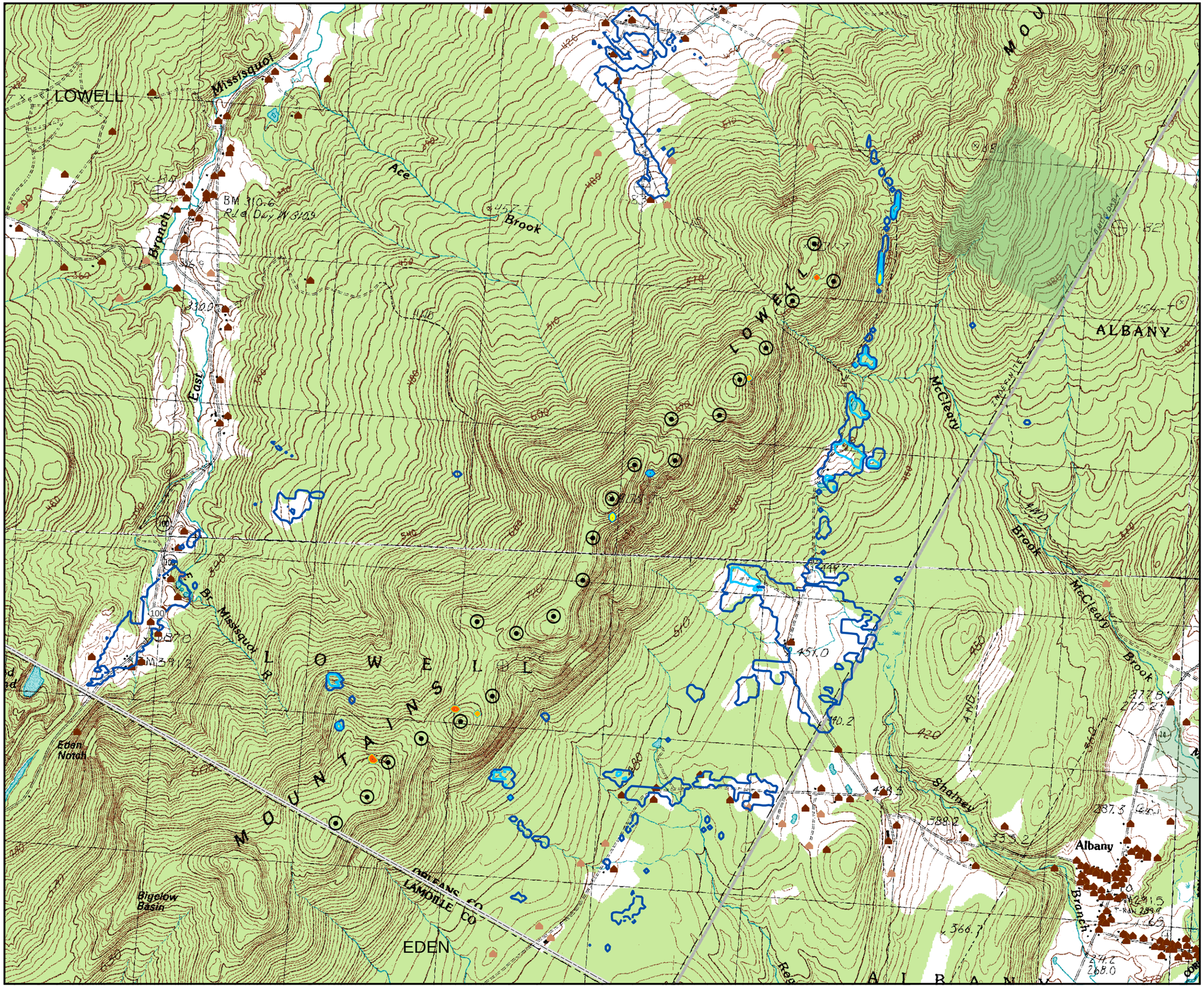

Kingdom Community Wind
Orleans County Vermont

Shadow Flicker Figure 2

Shadow Flicker Analysis - "Expected Case"
Within 2000 meters of wind turbine locations
National land cover
Sunshine probablity
Joint wind speed and direction frequency

Modeled: Twenty-one GE 2.5XL wind turbines

GE 2.5XL turbine location (4/2010)

"Expected Case" Hours per Year Contours

- 1 hr/yr
- 10 hrs/yr
- 25 hrs/yr
- 50 hrs/yr
- 100 hrs/yr
- 200 hrs/yr

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- Residential structures
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